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Runway veer-off accidents: Quantitative risk assessment and risk reduction measures

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ABSTRACT

The attention to airport safety-related issues has grown fast in recent decades. The experience gained in these themes reveals the importance of assessing and mitigating the accident risk in the airport context. This work presents a quantitative risk assessment method useful to calculate the current level of risk for different runway codes and types of movement. The model consists of cumulative probability distributions, which describe the final position of an aircraft after a veer-off, and a damage model, which considers statistical mechanical damages and injuries observed in the examined database. The current levels of veer off risk range between the orders of magnitude 10^{-8} and 10^{-10}, varying for runway code and type of movement. Geotechnical and geometrical characteristics of the Cleared and Graded Area (CGA) width play a fundamental role in reducing veer-off risk. An enlargement of CGA could be an effective strategy, as demonstrated by the carried-out sensitivity analysis: the obtained results demonstrate important reduction (up to 63%) of the risk of the main landing gear departing beyond the CGA (R_{CGA_GEAR}). For instrument runways, the average reduction of R_{CGA_GEAR} is sensitive, even when the CGA enlargement is only 5 m-wide (i.e. 10% for landing and 7% for take-off). The strategy proposed by the authors does not require modification of airplane technologies and safety devices for passengers, moreover it complies with the ICAO investigation for mitigating consequence of this type of accidents. Therefore, the results of the study could have a significant impact on the risk management in airport.

1. Introduction

Forecasts of continued growth into the next decades (Boeing, 2016) put a strain on airport capacity (European Transport Safety Council, 1999). Facing an increment of traffic turns into even more challenges regarding safety of operations: this challenge is not limited to the airport field, but it represents a crucial aspect also for road traffic (World Health Organization, 2015).

With air traffic projected to double by 2030, safety risks must be addressed proactively to ensure that a significant expansion of air transport demand is carefully managed and supported through strategic regulatory, infrastructural developments, and the issuing of safety procedures (International civil aviation organization, 2013a).

The International Civil Aviation Organization (ICAO) requires that all companies operating on certified aerodromes keep a Safety Management System (ICAO, 2013a), SMS, in place within their organizations (Airports Council International, 2015). According to the European regulation no. 139/2014 (European Commission, 2014), the aerodrome operator shall implement and maintain an integrated management system which should include a formal process that ensures analysis, assessment and mitigation of safety risks. The aerodrome operator shall submit a safety assessment to the competent civil aviation Authority which should evaluate the conclusion in order to ensure compliance with the relevant requirements for the operator. Risk assessments are necessary at the initial request of issuing certificate; the European Aviation Safety Agency (EASA) requires these analyses also in case of a request for prior approval for a change which may involve organizational, operational or infrastructural aspects (EASA, 2014a). In line with the ICAO Annex 19 requirements (ICAO, 2013a), relevant provisions were issued by EASA (2014b; 2016a,b). Aerodrome operators shall identify the hazards, decide who may be harmed and how, evaluate risks and decide whether the existing control measures are adequate or whether more should be done (Airports Council International, 2010). At the end of the process the operator shall record the findings and review the assessment, by revising it if necessary. Certainly, this procedure requires a detailed evaluation from different perspectives of the subjects involved. A good-quality safety management design for airport infrastructures needs an accurate methodology

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to evaluate risks and prevent accidents (Canale et al., 2005; Wong et al., 2009a,b; Kirkland et al., 2004; Di Mascio and Loprencipe, 2016). Quality of safety analysis is based on hazard identification and implemented methodology for further safety risks analysis (Ayres et al., 2013). Nowadays, different methods and tools are used in aviation safety risks analysis (ARCP, 2011): statistical analysis, trend analysis, normative comparisons, simulation and testing, expert panel, cost-benefit analysis (Čokorilo et al., 2014; Ericson, 2016; NLR, 2006). Those methods are based on primary and secondary hazard analysis techniques. The primary hazard analysis techniques are full-fledged or complete methodologies whilst the secondary techniques are limited in their hazard identification ability since they are mostly developed to identify main hazards (not all hazards within the system).

Veer-offs are a type of runway excursions considered by the European Aviation Safety Agency (EASA, 2016a,b). A runway excursion occurs when an aircraft departs the end or side of the runway surface during a take-off or a landing: it consists of an overrun for the former type and a veer-off for the latter one. Runway excursions that occur during operations on paved runways are one of the main types of accidents in airports (International Air Transport Association, 2011a,b; Post, 2015). Therefore, they require implementation of primary techniques aiming to identify all generic hazard as a basis for safety risks evaluation and control or mitigation (EASA, 2013). The ICAO Annex 14 provides recommendations for acceptable consequences in case that an aircraft runs off the side of the runway (ICAO, 2013b). Specifically, the Aerodrome Design Manual Part 1. 5.3.22 specifies that the runway strips: *"[…] should be graded in such a manner as to prevent the collapse of the nose landing gear of the aircraft."* (European aviation safety agency, 2014c). In addition, the surface of this cleared and graded area (i.e. CGA) has to provide sufficient bearing strength to avoid damage to the design aircraft. (ICAO, 2013b; Airports Authority of India, 2010). At this purpose, in many countries, national specifications require special risk evaluations, to add to those required by ICAO in ordinary conditions. For example, the Italian Civil Aviation Authority (ENAC) in case of insufficient bearing strength of the strip, requires a runway veer-off risk assessment (Italian Civil Aviation Authority, 2014). Existing methods available in the literature provide an estimate of risk, but they consider the system airplane-airport overlooking the human effects. For example, Kirkland et al. (2004), Ayres et al. (2013), and ACRP (2014) elaborated interesting probability and damage models applied to runway accidents. However, they do not consider the people on board, and their concept of veer-off is strictly related to the collision of the airplane with an object (e.g. their variables are: obstacle type, lateral aircraft size) (ACRP, 2014), and to the consequence on the infrastructure (e.g. size of debris area) (Nationaal Lucht-en Ruimtevaartlaboratorium-NLR, 2000). However, the lateral excursions examined by the authors in previous studies (Moretti et al., 2017a,b) demonstrate a veer-off could be catastrophic even when an obstacle is absent, and the airplane ends its run within the strip. Indeed, not only physical obstacles interfere with the veering off aircraft, but the pilot-weather-airplane-airport system. Moreover, most of the methods proposed in the literature to evaluate the risk do not allow the quantification of the risk. The Federal Aviation Administration (FAA) Office of Flight Standard Services introduced safety performance indicators (i.e. fatal accident per 100,000 departures, accident per one million passenger miles, fatalities per 100 million persons on board) which needs a synthesis to carry out a comprehensive analysis (FAA, 2012).

Therefore, this study presents a method to assess the probability and the risk of a veer-off accident at any airport, considering its effect on the occupants. Veer-off accidents occurred within the period 1980–2016 throughout the world were collected to compose a statistical database. It allowed defining analytical frequency and damage models, whose combination gives to the user a quantitative and reliable risk value. The application of the method permits to assess the current veer-off risk, to identify the most critical conditions, and to quantify the effectiveness of protection strategies that could be adopted for reducing the veer-off risk. At this purpose, the study focuses on the CGA role to mitigate the risks when a veer-off occurs. Therefore, it can be used to implement a SMS at airports varying the width of the CGA.

As observed, this work overcomes some of the main limitations of existing risk analyses conducted on airport accidents, which makes it a relevant contribution to the current state of knowledge on this topic. It is also important to highlight that the approach herein used could be efficiently replicated to conduct similar analysis for other airport accidents and, consequently, it constitutes a useful tool for the achievement of the safety policies stipulated by ICAO (2009).

2. Method

This study considered 305 veer-off events (accidents or serious incidents), occurred to passenger/cargo flights over 30 Mg within the period 1980–2016 (Agenzia Nazionale per la Sicurezza del Volo, 2016; Airdisaster.com, 2016; Australian Transport Safety Bureau, 2012; Aviation safety network, 2005; Boeing, 2000, 2002, 2003, 2006, 2010, 2012, 2013, 2014, 2015, 2016, 2017; General Aviation Manufacturers Association, 2005; National Transportation Safety Board, 2014). Accident data reports allowed the statistical analysis of the final position of the airplane at the end of the accident. Having the worldwide number of yearly movements NM_i, the authors calculated the frequency of veer-off accidents during the examined period according to Eq. (1):

$$\mathrm{f}=\frac{\sum_i NA_i}{\sum_i NM_i} \tag{1}$$

where NA_i is the number of veer-off accidents occurred during the year i between 1980 and 2016.

The final stopping location of the aircraft at the end of veer-off accidents permitted to distinguish three main scenarios:

- veer-off over the runway (RWY), with the external gear over the RWY;
- veer-off over the CGA, with the external gear over the CGA, but the wing tip inside the strip;
- veer-off over the strip, with the external gear or the wing tip over the strip.

Having the statistical database, the authors defined the transversal and longitudinal distribution probability curves related to the final position of the aircraft. A negative exponential distribution function of the cumulative probability describes the probability p that at the end of a veer-off the aircraft travels beyond longitudinal edges of the runway and its main landing gear stops at a certain distance x measured from the RWY centerline (Moretti et al., 2017c). This function is defined as (Eq. (2)):

$$\mathrm{p}= e^{-kx} \tag{2}$$

where k is a calibration coefficient.

This approach differs from that proposed by ACRP (2014), which considers the distance from the runway edge. The choice of the authors is in favor of safety. When a "little" airplane veers off moving on a "big" RWY (i.e. the airplane is not the design airplane for the alphabetical classification of the RWY), the lateral excursion calculated from the RWY edge is shorter than the real lateral excursion, and it would result in the underestimation of the event.

Combining the frequency f with the probability p, the authors obtained a function which describes the probability P that a veer-off accident occurs and at the end it is at a certain distance from the centerline. Eqs. (1) and (2) describe two independent events, therefore P is defined according to Eq. (3):

$$\mathrm{P}= f\cdot p \tag{3}$$